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Interim Development Report No. 3

29 MARCH 1963

A LOW-NOISE, MULTIPLE-FUNCTION, X-BAND TRAVELING-WAVE TUBE

This Report Covers the Period

1 December 1962 through 28 February 1963

Contract NObsr-87535
Project No. SR008-03-4
Task No. 9293 Sub.

DEPARTMENT OF THE NAVY
BUREAU OF SHIPS
ELECTRONICS DIVISIONS
WASHINGTON 25, D.C.

by
RADIO CORPORATION OF AMERICA
Electron Tube Division
Microwave Tube Operations
HARRISON, N. J.

RADIO CORPORATION OF AMERICA
ELECTRON TUBE DIVISION
HARRISON, NEW JERSEY

April 26, 1963

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HARRISON, N. J.

Prepared by: G. Hodowanec, C. Bacher, R. McMurrough

Approved by: H. Wolkstein

ABSTRACT

This report describes the work done during the third quarter of a program to design and develop the RCA Developmental Type A-1281 low-noise, multiple-function, X-band traveling-wave tube.

The major effort during this period was expended in the experimental evaluations of the design approaches proposed for obtaining a simple, but reliable, tube design meeting the program objectives. Emphasis was placed upon the compression-sheath-supported helix structures and associated transducer systems, the magnetic circuits, the limiter-section design parameters, and the video-detection circuitry.

While some design refinements are still contemplated, the overall final tube design has been established and will now be evaluated in hybrid glass-metal-ceramic structures and also completely integrated metal ceramic structures.

Meanwhile, metal-ceramic technology studies, aimed at simplifying and increasing the reliability of the seals, continues. In addition, the final tube design packaging is being worked out and necessary vendor-provided parts are being ordered in preparation for the fabrication of the ten tubes desired.

TABLE OF CONTENTS

Part		Page
I	PURPOSE AND FACTUAL DATA	1
	1. Purpose	2
	A. Objective Specifications	2
	B. Specific Tasks	4
	2. General Factual Data	6
	A. Identification of Technical Personnel	6
	B. References	7
	C. Measurement Procedures	7
	1. Gain and Power Measurements	7
	2. VSWR Measurements	8
	3. Noise Figure Measurements	8
	4. Video Output Measurements	8
	3. Detailed Factual Data	10
	A. Development of RCA A-1281 Multiple-Function Tube	10
	1. Design and Evaluation of the Microwave-Amplifier Section	10
	a. RF Coupling System	11
	b. Helix Assembly	12
	c. Electron Gun	14
	d. PPM Focusing Structure	18
	e. Evaluation of Experimental Glass Tubes	21
	2. Design and Evaluation of the Video Section	29
	a. Video Detection	29
	b. Video Amplification	32

TABLE OF CONTENTS (CONT.)

Part		Page
	3. Design and Construction of the Metal-Ceramic Tube..	38
	a. Electron Gun	38
	b. Slow-Wave Structure	39
	c. Video Section	39
	d. Overall Tube Package	41
	B. Performance and Schedule Chart	42
	C. Conclusions	42
II	PROGRAM FOR NEXT INTERVAL	46
	REPORT DISTRIBUTION LIST	48

LIST OF ILLUSTRATIONS

Figure		Page
1	RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Test setup for measuring gain, rf power output, and video output..........................	9
2	RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Schematic drawings of the type A (drift-field lens) low-noise electron gun...................	15
3	RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Schematic drawings of helix structures..	23
4	RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. RF performance of the linear-output helix section of two experimental tubes..............	24
5	RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Power output-vs.-power input characteristics of the limited-output helix section..........	26
6	RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Performance of an experimental tube in the dynamic video-detection tests...................	30
7	RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Performance of the secondary-emission video amplifier...................................	35
8	RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. DC supply voltages that, at present, are expected to be required in the final tube.......	40

PART I

PURPOSE AND FACTUAL DATA

SECTION 1

PURPOSE

This program is being carried out to design and develop a low-noise, multiple-function, metal-ceramic traveling-wave tube intended for simultaneous operation as a linear X-band amplifier, limiter, and video detector in an electronic countermeasures system. The objective tube has been designated RCA Developmental Type A-1281. Ten A-1281 tubes that meet all the objective requirements are to be fabricated and delivered at the conclusion of the program. This work is being done for the Department of the Navy, Bureau of Ships Electronics Divisions, under Contract NObsr-87535.

A. Objective Specifications

To satisfy the rigid requirements of the system in which the A-1281 tube is expected to perform its multiple functions, it is essential that the final tube design be oriented toward meeting the following objective specifications, as given in BuShips P.R. 691A1-29158(Q):

Electrical Characteristics

Overall Tube

Frequency range	7 to 11 Gc
Input VSWR	2 to 1 (max.)
Output VSWR	2 to 1 (max.)
Spurious output	With no rf signal applied, the rf output at any frequency (1-Mc bandwidth) across the band shall not exceed -10 dbm.

RF shielding	With the tube operating (but no rf input) and immersed with arbitrary polarization in an rf field with a uniform power density of 1 watt per square meter, the output of the tube, with its input connected to a load that provides a VSWR of 2 to 1, shall be less than -20 dbm over the frequency band.
Linear Amplifier Section	
Small-signal gain	35 db (min.)
Gain flatness	± 2 db over the band
Saturated power output	10 mW CW (min.)
Terminal noise figure	10 db (max.)
Isolation and cutoff	60 db (min.)
Control grid	
Voltage swing	50 volts (max.)
Capacitance	20 uuf (max.)
Beam voltage	1300 volts (max.)
Limiter Section	
Gain	50 db (min.)
Saturated power output	10 mW (min.)
Flatness of limited output	± 3 db for an rf input of -40 to 0 dbm
Video Detector Section	
Video output	1 volt ± 3 db across 300 ohms with an rf input of -40 to 0 dbm

Environmental Capabilities

Temperature	
Operating	$-55^{\circ}C$ to $+85^{\circ}C$
Storage	$-55^{\circ}C$ to $+125^{\circ}C$

Cooling	Forced air
Shock	30 g; 11 milliseconds
Vibration	10 g; 5 to 200 cps

The ten final tubes are to be metal-ceramic structures that are focused in a periodic-permanent-magnet (ppm) stack capable of operating over the temperature range -55°C to +85°C.

B. Specific Tasks

To expedite the development of the A-1281, the special technological studies related to metal-ceramic structures and ppm-focusing techniques are being carried out concurrently with the design of a traveling-wave-tube circuit that will exhibit the unique combination of dual rf output characteristics and video detection in accordance with the objective specifications. As a result, the evaluation of the rf performance of the tube circuit will not be dependent upon the development of subsidiary fabrication techniques.

The major tasks to be performed in the development of the RCA A-1281 multiple-function traveling-wave tube can be broken down into four general phases of work as follows:

Phase 1 - Basic Design Studies and Exploratory Tests

In this phase, design studies and exploratory tests will be conducted to determine the best possible basic design of the objective tube in relation to system requirements and simplicity and reliability of construction. The various facets of the overall tube development, such as the low-noise electron gun, the linear-and limited-output helix circuits, the rf coupling system, the video section, ppm focusing requirements, and metal-ceramic technology, will be investigated independently. Thus, the results from any one investigation will not be conditioned by progress in other areas. Each aspect of the development will be oriented, however, toward the attainment of all the objectives of the entire program.

Phase 2 - Construction and Evaluation of Experimental Glass Tubes

The work in this phase will be done concurrently with the latter stages of Phase 1. This work will implement the results of the earlier phase in experimental tubes of glass construction. The object is to evaluate experimental glass tubes into which the various tube functions have been integrated as required for the system. The design of the experimental glass tubes will be modified and refined, as necessary, to enable a simple conversion from the glass type to the metal-ceramic type of tube structure.

Phase 3 - Development of Prototype Metal-Ceramic Tubes

During this phase, metal-ceramic tubes, assembled into prototype ppm focusing packages, will be designed, constructed, and evaluated. The design for these metal-ceramic tubes will be based on that of the glass tubes providing the best performance during Phase 2. The work in this phase will result in an interim tube that meets most, if not all, of the design objectives for this program.

Phase 4 - Design, Construction, and Delivery of Final Metal-Ceramic Tubes

The effort during this phase will be directed toward establishing the final design for the multiple-function, metal-ceramic tube and in a limited production run leading to the delivery of the ten sample tubes required. Detailed manufacturing drawings and processing data will be prepared.

The overall effort in this program is directed toward the successful development of the objective multiple-function tube without compromise of any performance requirements or of product reliability. Accordingly, a continuous survey of the literature on related programs will be made throughout the program, and consultations will be held whenever necessary to solidify and clarify specific design approaches or to solve specific problems related to the overall development effort.

SECTION 2

GENERAL FACTUAL DATA

This section of the report contains: (1) The names and titles of technical personnel and the number of man-hours spent by each of them on this program during the third quarter; (2) A list of the publications to which references are made in other sections of the report; and (3) Descriptions of the procedures used for making various measurements.

A. Identification of Technical Personnel

During this quarter, the following engineers and technicians worked, for the number of hours shown, on the development of the RCA A-1281 multiple function traveling-wave tube:

Name and Title	Hours
Traveling-Wave Tube Design and Application	
R. McMurrough, Engineering Leader	24
G. Hodowanec, Engineer (Project Leader)	436
C. Bacher, Engineer	301
R. Bridge, Technician	345
P. Yanchusk, Technician	400
Chemical and Physical Laboratory	
E. Thall, Engineer	59
Z. Piotrowski, Technician	9

B. References

Some of the information and assumptions contained in this report are based on results and conclusions reported in the publications listed below. (Superscript numerals inserted in the body of the texts serve as references to the appropriate publication.)

1. Smullin, L. C., and Fried, C., "Microwave Noise Measurements on Electron Beams," 1954 Symposium on Fluctuation Phenomenon in Microwave Sources, Western Union Auditorium, New York, Nov. 1954.

2. Chang, K. K. N., "Periodic Magnetic Field Focusing for Low-Noise Traveling-Wave Tubes," RCA Review, September 1955.

C. Measurement Procedure

The following paragraphs describe the procedures and test setups used in measuring: (1) the gain and power output of the multiple-function tube, (2) the VSWR of the input and output circuits, (3) the terminal noise figure, and (4) the response of the video circuit.

1. Gain and Power Measurements

Conventional techniques are used in the measurement of the small-signal gain and the power output of the traveling-wave tube. The actual setup being used is shown in Fig. 1. The output of the signal generator is fed through a 3-db directional coupler which enables monitoring of the generator output at some level, usually 0 dbm. The inclusion of the absorption-type wavemeter enables accurate frequency calibration of the test signal. The 0-50 db calibrated attenuator enables a direct determination of the tube input power level. Output power levels are read directly on the respective power bridges. Tube gain and power output is, thus, readily obtainable under a wide range of operating conditions.

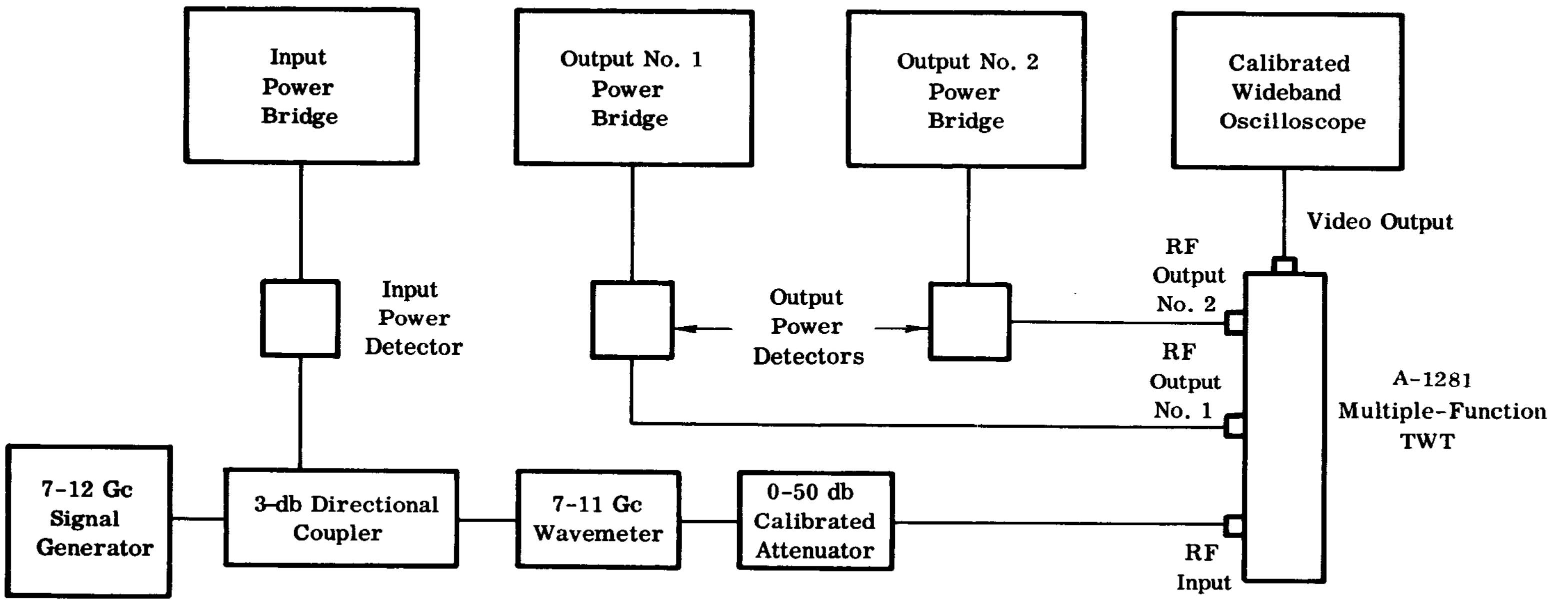


Figure 1 — RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Test setup for measuring gain, rf power output, and video output.

2. VSWR Measurements

The measurement procedures and test setups being used for evaluating the VSWR response of the RCA A-1281 tube were described in Interim Development Report No. 1.

3. Noise-Figure Measurements

The measurement procedures and test setups being used for evaluating the noise performance of the RCA A-1281 tube were also described in Interim Development Report No. 1.

The automatic noise-figure measuring setup is now being used exclusively on this program since the accuracy of measurements (order of $\pm$ .25 db) is sufficient in the range (8 to 12 db) over which the measurements will be made.

4. Video Output Measurements

The video output is displayed directly on a calibrated wideband oscilloscope screen, as shown in Fig. 1. This setup enables not only the determination of the video output level as a function of input drive, but also displays such factors as pulse rise time and frequency response.

SECTION 3

DETAILED FACTUAL DATA

This section of the report describes, in detail, the work done during the third quarter of the program to develop the RCA A-1281 metal-ceramic, low-noise, multiple-function, PPM focused, X-band traveling-wave tube. The emphasis during this period was placed upon the completion of experimental evaluations of the design approaches and techniques that are being used. (These approaches were previously discussed in Interim Development Reports No. 1 and No. 2.)

Work was also begun on the various facets of the final tube design. Design modifications, reflecting the experience and knowledge gained in the experimental tests, were made, as necessary, in order to insure the final successful development of the required tube design.

A. Development of the RCA A-1281 Multiple-Function Tube

The traveling-wave tube being developed during this program is required to perform two basic functions: (1) microwave-signal amplification, producing both a linear and a limited X-band output and (2) video-signal detection, supplying an essentially constant-amplitude video pulse for a wide variation in the magnitude of the input signal.

1. Design and Evaluation of the Microwave-Amplifier Section

The development of the microwave-signal (7 to 11 Gc) section of the A-1281 tube is being carried out independently of that of the video-signal section. In the approach being followed, the various components and subassemblies that comprise the microwave-signal section are experimentally evaluated in glass tubes or in hybrid glass-metal-ceramic tubes to prove out the particular aspects of their design in respect to both performance capability and adaptability to the final metal-ceramic tubes. The following paragraphs describe the progress made in the design of the various elements of the microwave-signal section of the A-1281 tube.

a. RF Coupling System

The large X-band waveguide type of rf signal couplers, described in Interim Development Report No. 1, will be used in the final A-1281 tubes. The dimensions of the choke section of the couplers have been adjusted to be compatible with the final design of the ppm focusing structure and to allow adequate room for passage of the final version of the metal-ceramic video section through it during the assembly of the overall tube package.

A folded-back type of antenna structure that is specially tapered to assure a minimum mismatch has been selected to couple the rf power to and from the helices of the A-1281 tube. The proposed antenna structure is of the same diameter as the compression-support sheath of the helix and is assembled onto the helix structure using the same procedure. (See paragraph on "Design and Construction of the Helix Assembly" in Interim Development Reports Nos. 1 and 2.) This method of assembly results in an extremely rigid structure.

The larger-diameter, tapered, folded-back antenna structure was chosen for the final tubes because it provides a significantly greater coupling bandwidth with the proposed final-design waveguides and a shorter overall tube length. Cold-test measurements on this type of structure have shown that a VSWR of 1.7 to 1 is readily obtainable over the frequency range 7 to 11 Gc; and for some structures, VSWR's of less than 1.3 to 1 were obtained over the full octave of 6 to 12 Gc. In the measurements on the structures with the lower VSWR's, it was found that a mismatch can occur at about 10.4 Gc because of the propagation of the $TE_{2,0}$ Mode in the large X-band waveguides. However, this mismatch can be reduced sufficiently, by the proper positioning of antenna with respect to the waveguide geometry, so that its effect on tube performance is negligible.

b. Helix Assembly

The helix assembly of the multiple-function traveling-wave tube consists of two separate helix sections. Each section has its individual output circuit and is electrically isolated from the other so as to enable individual adjustment of helix potentials. Coupling between the two helices is only by means of the electron beam.

(1) Helix Design Parameters

The evaluations of the experimental tubes fabricated thus far continue to show small signal gains of 9 to 10 db per inch for beam currents in the order of 600 ua. These data indicate that the final-design linear-amplifier section will provide the 36 to 40 db of small signal gain desired and that the saturated power output will be between 10 and 20 mW.

Minor adjustments in the final-design helix parameters are planned as a result of the dynamic tests of a video detector. (See discussion of tube VF-1 in paragraph 2, "Design and Evaluation of the Video Section.") These tests indicated that it is possible to operate the tube with the desired depression of the collector potential. On the basis of these results, the helix operating voltage is being increased from 1150 to 1250 volts. This change will improve the high-frequency response of the helix and also will enable an improvement in the ppm focusing characteristics.

In addition, a revised helix design, with the mean diameter increased by 0.010 inch, is being evaluated. This increase in the helix diameter is contemplated to simplify the focusing of the beam in final-design tubes as well as to reduce beam interception in the helix entrance regions. Excessive beam interception in this region severely degrades the tube noise performance.

All the design revisions mentioned above do not change the basic helix parameters and are readily adaptable to the compression-sheath-supported helix structures now being used.

(2) Construction of Helix Assemblies

The compression-sheath method of supporting the helices in the A-1281 tubes (described in Interim Development Reports Nos. 1 and 2) has been perfected. On the basis of the evaluations of several possible materials, beryllium copper was selected as the optimum material for the compression sheath in the final metal-ceramic tubes. This material has sufficient elasticity to prevent any permanent effects when distorted to permit insertion of the helix and has adequate mechanical strength to insure strong support of the helix. Also, it can be readily secured in the shape and size required.

The construction of several sample structures has proved that the use of the beryllium-copper sheath results in extremely rugged, highly reproducible helix assemblies. In addition, the entire assembly can be hydrogen-fired just prior to being assembled into the tube envelope. The first tests of such a helix assembly in an actual tube (Tube VF-1, discussed in the paragraph on the video section) has shown a substantial improvement in the helix alignment, as indicated by the improved focusing, and no signs of any gas being evolved from the helix assembly.

The compression-sheath-supported helix also enables relatively easy adjustment of the parameters of the limited-output helix section. These include such adjustments as changes in helix length or TPI, in attenuator length and/or position, and in the dielectric loading on the helix. The initial tests of the limiter action have indicated that these types of changes will be necessary in order to achieve the limiting action desired in the final-design of the tube.

c. Electron Gun

Figure 2(a) shows a schematic of the basic electron gun now being used in the A-1281 tubes. This gun is the type A structure described in Interim Development Report No. 2, and it is normally operated with the drift-field configuration shown in the figure. A modified version of this basic gun structure was used in three interim-design tubes (tubes C-1, D-1, and VF-1) that were fabricated, primarily, for verification of the basic parameters selected for the helix circuit. (See paragraph e, this section.)

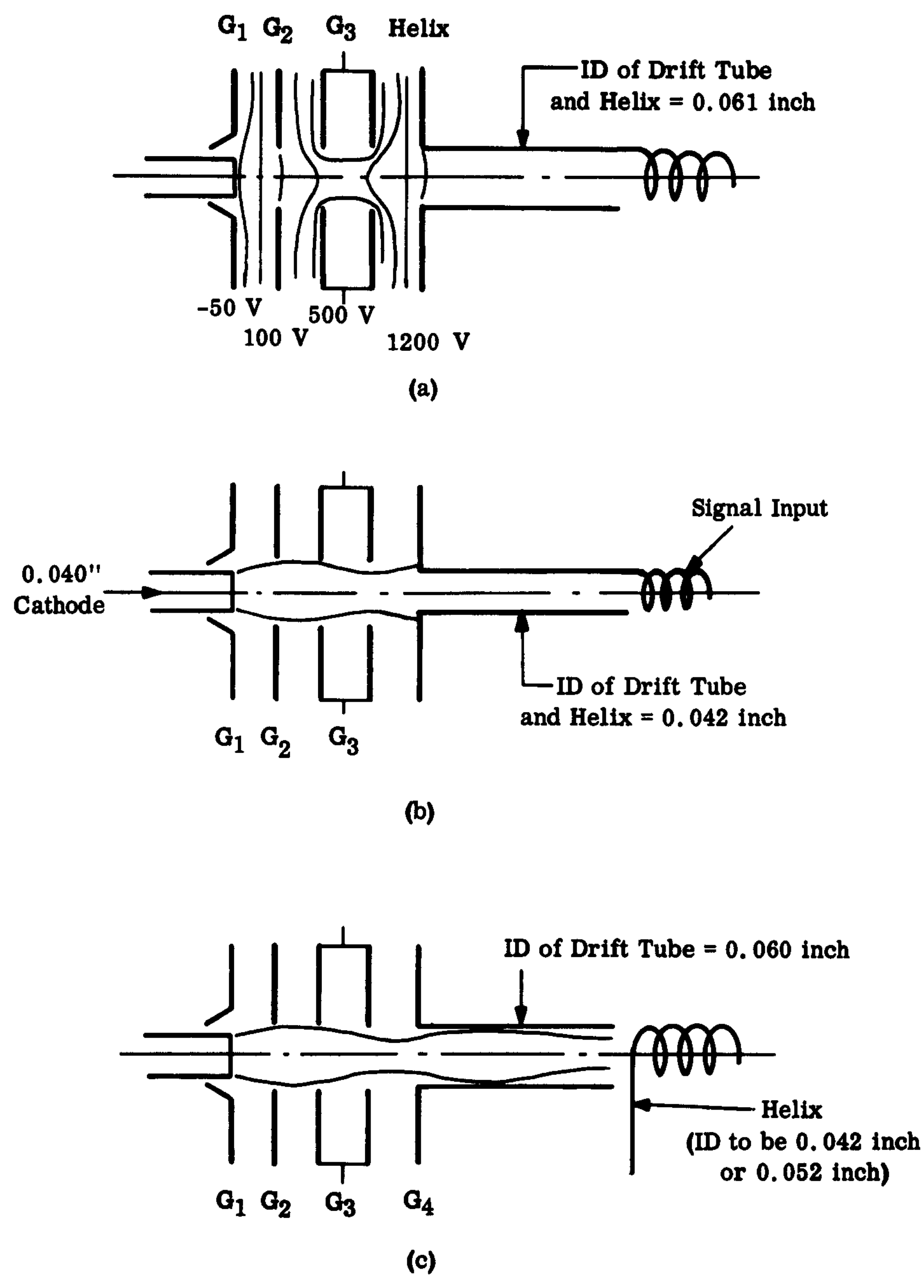


Figure 2 — RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Schematic drawings of the type A (drift-field lens) low-noise electron gun. (a) Electrode arrangement and electric field distribution of the basic gun structure. (b) Apparent beam configuration obtained in the exploratory tests of interim tubes. (c) The beam configuration expected in the final tube.

The verification tests for the helix were carried out concurrently with the work to perfect the compression-sheath helix support techniques. Therefore, to expedite the verifications, the helices in two of the interim tubes (C-1, and D-1) were supported by the shrunk-glass technique; as a consequence, the inner diameter of the drift tube of the electron gun used in these tubes had to be reduced to 0.042 inch. Figure 2(b) shows a schematic of the modified gun structure.

The interception of the electron beam by the drift tube was found to be excessive. The increased beam interception stems from the fact that, in the low-noise electron gun, the cathode is immersed in a magnetic field of about 375 gausses which causes the beam to scallop in the manner depicted in Fig. 2(b), and the reduced inner diameter of the drift tube is too small to encompass the expanded regions of the beam. Under the best focusing conditions, about 50 per cent of the beam in the interim tubes was intercepted by the drift tube, and about 2 per cent of the beam was collected as elastically reflected electrons by the drift-field lens elements. As a result, the noise performance of these tubes was severely degraded.

A significant reduction in the helix interception of the beam was observed in tube VF-1, which used a compression-sheath-supported helix structure in conjunction with the 0.042-inch-diameter drift tube. In this tube, the beam transmission was about 70 per cent. However, in the experimental tubes using the drift tube and helix with a 0.061-inch inner diameter, beam transmissions of better than 98 per cent (up to 1 ma of collector current) were obtained using the same gun geometry and focusing package. No evidence of elastically reflected electrons was found in these early exploratory tests.

The stable terminal noise figures of the interim-design tubes ranged from 16 to 18 db, as measured by a Hewlett-Packard Model 340B automatic noise-figure meter. It was possible, however, to cause a sharp dip of at least 3 db in the noise figure by transient adjustments of the helix potential. This latter behavior indicates that apparently the position of the rms noise minimum is shifted greatly by the wide variations in the "reduced" plasma wavelengths that can occur in the reduced-diameter drift tube.

In the interim tubes, the length of the drift tube was adjusted to equal a quarter plasma wavelength, to the signal entrance point with the plasma reduction factors considered a second order effect. However, under the existing conditions in the drift tube region, the reduction factors were not second order effects; as a result, the drift length was too short to properly locate the rms noise minimum at the signal input. It was possible to momentarily phase the noise minimum at the proper position by transient adjustments of the helix potential; had it been possible to stabilize the noise minimum at the desired position, the terminal noise figure of the interim tubes would have been in the order of 13 to 15 db.

Terminal noise figures between 10 and 12 db had been anticipated for the interim tubes since the low gain (4 to 6 db) of the input portion of the linear helix section used in these tubes was expected to increase the noise figure 2 to 3 db above the design objective of 8 to 10 db. This is due to the "second stage noise" contribution of the output section of the linear section helix. In addition, the noise figure was increased at least 3 db by the partition noise introduced by the 50 to 60 per cent interception of the beam on the drift-tube entrance.[1] Thus, an overall increase in noise figure of 8 db can be attributed to the interim conditions, which indicates that the basic noise figure was probably in the order of 8 to 10 db.

The scalloping of the beam and the attendant increase in the drift-tube interception can be reduced by using a smaller-diameter cathode. However, in the final design of the electron gun, the drift-tube interception may not be a problem, since the inner diameter of the drift tube, as shown in Fig. 2(b), will be increased to 0.060 inch, essentially the same as in the early exploratory tubes. Figure 2(b) also shows that in the final design the inner diameter of the helix can be made either 0.042 or 0.052 inches. This is made possible through the use of the compression-sheath-supported helix structure. Separate control of the drift tube and helix potentials in the final design tubes will also enable better phasing of the rms noise minimum. Hybrid tubes (glass, metal, and ceramic structures) containing final-design helices and electron guns are now being fabricated for use in verifying the predicted noise performance before the emphasis is shifted completely to metal-ceramic tubes.

d. PPM Focusing Structure

During the third quarter, considerable effort was expended on refinements to the proposed PPM focusing structure. The original exploratory type of focusing package (based upon the concepts of K.K.N.Chang[2]), while apparently giving satisfactory focusing with the exploratory tubes, proved inadequate for the much tighter focusing requirements of the smaller helix diameters of the final-design tubes. The evaluations of tubes C-1, D-1, and VF-1 were, thus, delayed while the PPM focusing problem was studied and resolved.

The final design evolved for the focusing package, uses a 0.52-inch period in the main focusing field and a 0.46-inch period in the entrance field. The uniform gun field is roughly 90 per cent of the peak value of the entrance field, which is about 400 gausses in the proposed focusing package. The critical magnetic circuits (i.e., the gun field, the transition field, and the entrance period) are assembled in a simple, straightforward structure and appear to be easily reproducible. Alnico VII-A magnets are used in the main PPM stack, while temperature-compensated Indox magnets are used for the gun and the entrance-period magnetic fields. Alnico VIII gun-field magnets are also being secured for evaluation and possible use in the final design.

The tests of a final-design type of focusing package indicated that it would be highly satisfactory for focusing the A-1281 tubes. This structure had provided extremely good focusing of the early exploratory types -- beam transmissions in excess of 98 per cent were obtained. Interim-design tubes C-1 and D-1, which could not be focused in the original exploratory type of ppm test package, were focused in this final-design-type package with about 50 per cent transmission (at a cathode current of about 800 to 900 ua).

A substantial improvement in beam transmission was observed when interim tube VF-1 was focused in the final-design focusing package. This tube, which used the same electron gun (drift tube with a 0.042-inch inner diameter) as that used in tubes C-1 and D-1 but used a compression-sheath-supported helix structure instead of the shrunk-glass type used in the other tubes, was focused with about 70 per cent beam transmission (at a cathode current of about 1 ma). The better focusing is attributable to the better helix alignment possible with the compression-sheath helix assembly.

The experimental data obtained thus far indicate that excellent focusing will be obtained with the final-design focusing package. On the basis of these data, it is confidently expected that the final-design tubes, which will use essentially the same gun geometry as that of the exploratory tubes and will contain compression-sheath-supported helices, will be focused with better than 95 per cent beam transmission in the final-design focusing package.

The tapered-field focusing period with an idealized, 0.72-inch-period main PPM field, originally proposed for focusing the final A-1281 tubes, was found to be extremely sensitive to changes in beam current. Although a proper adjustment of the periods and fields could be worked out to compensate for this condition, the effort on the tapered-field structure was discontinued in view of the satisfactory performance and greater simplicity of the 0.52-inch-period focusing structure.

The remaining effort on ppm focusing will be directed primarily toward determining the best method of incorporating the focusing structure into a final-design package.

e. Evaluations of Experimental Tubes

In this phase of the work, the various design features proposed for the A-1281 tubes are evaluated in experimental glass and hybrid glass-metal-ceramic tubes before they are incorporated into metal-ceramic tube structures. The use of the glass and hybrid tubes in the initial evaluations permits this work to be carried out much more readily than would be possible in metal-ceramic tube structures alone and, thereby, greatly expedites the establishment of the basic design for the final metal-ceramic tubes.

During this third quarter, three experimental glass tubes were constructed and evaluated. Two of them, tubes C-1 and D-1, were used primarily to establish the final parameters for the helix. The third tube, a hybrid, Serial No. VF-1, was used in dynamic tests of the video section. The following paragraphs describe the important features and the performance of these tubes.

(1) Experimental Tube C-1

Tube C-1 contained a Type A electron gun with an 0.040-inch I.D. drift tube as discussed in paragraph c above. The three-rod helix structure used in the tube was supported in a close-fitting precision glass tube that was "shrunk" over the helix structure. The main helix dimensions of the tube are given in Figure 3(a). The short helix sections were selected primarily so that an existing capsule design could be used, since only verification of the helix parameters was desired in this tube.

Tube C-1 operated at its design helix voltage of 1150 volts and its small-signal gain was in the design range of 9-10 db/inch (at the 600 ua beam level). Beam transmission under these conditions was only about 50 per cent -- cathode current was 1.2 ma. The saturated power output was greater than 10 mW over most of the frequency range, but dropped off beyond 10Gc, largely because of the smaller beam size that resulted from the limiting action of the small I.D. drift tube aperture. The data for this tube are plotted in Fig. 4. The drop in gain below 7.3Gc and beyond 10.7Gc was largely associated with the deterioration in the rf match at the band ends.

The noise performance of tube C-1 was discussed in paragraph c. As indicated there, severe noise degradation resulted from the use of a small I.D. drift tube in the interim tube tests.

(2) Experimental Tube D-1

Tube D-1 contained the same electron gun, drift tube, and linear section helix as was used in tube C-1 and, in addition, contained a 1.400-inch length of active helix (with a separate output) following the linear section. All helices were of the same TPI and were internally tied so that operation of all helices was limited to a common supply voltage.

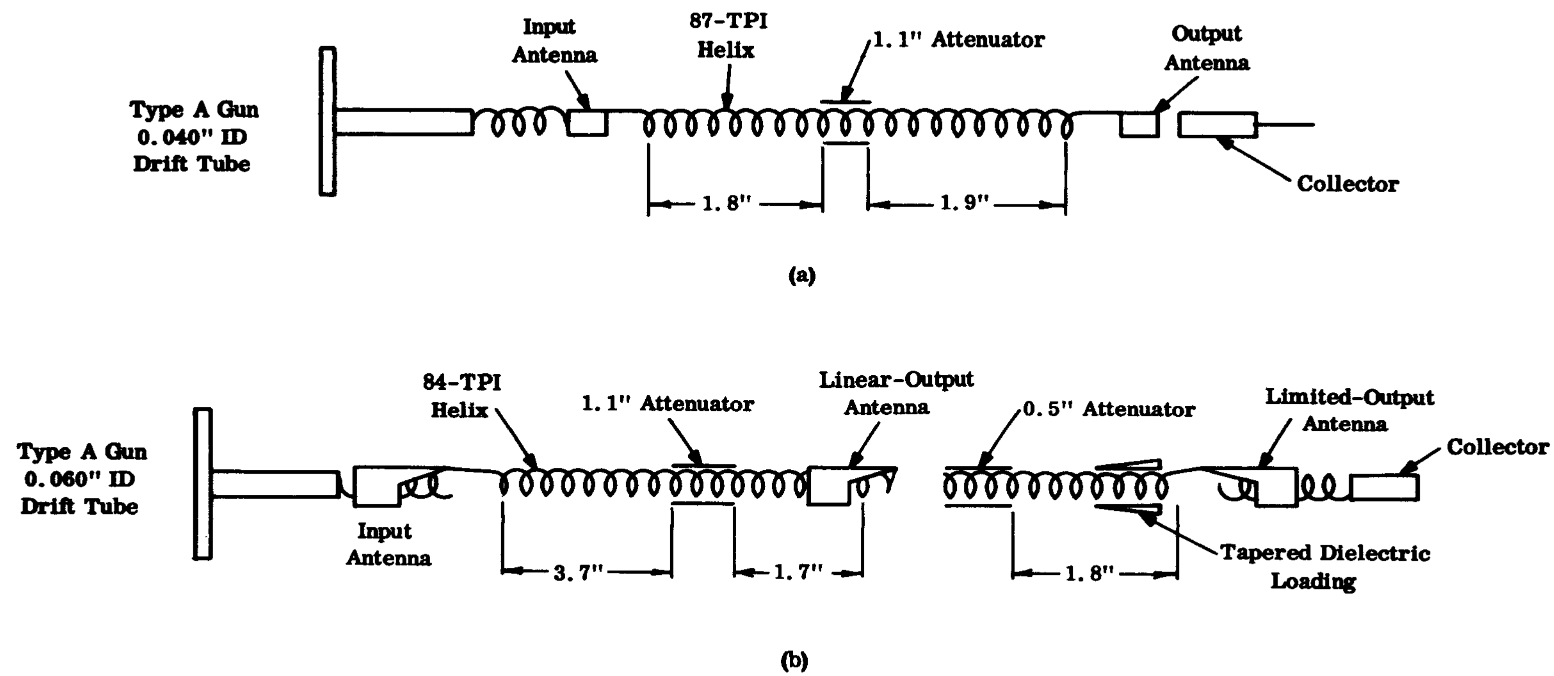


Figure 3 — RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Schematic drawings of helix structures. (a) Interim helix structure used in experimental tubes C-1, D-1, and VF-1. (b) The basic helix structure proposed for the final tubes.

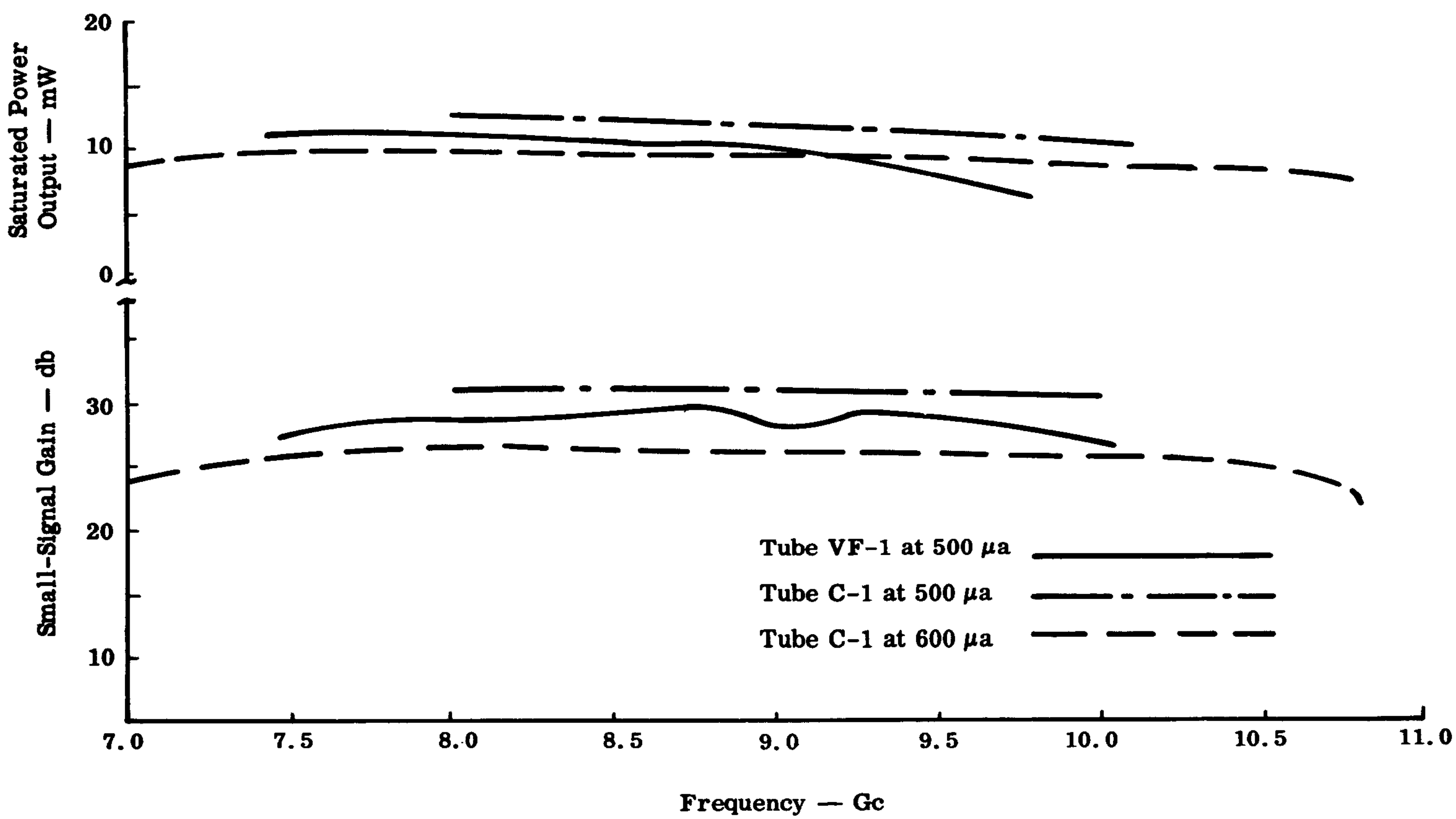


Figure 4 — RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. RF performance of the linear-output helix section of two experimental tubes (Tubes C-1 and VF-1).

Tube D-1 was constructed in this simplified form in order to expedite the determination of the nature of the power-saturation characteristics under conditions approaching those that will exist in the final design. The power-output characteristics desired for the final tubes are shown in Fig. 5(a).

It was not possible to fully exploit the capabilities of tube D-1 for two reasons: First, this tube contained the electron gun with the small-diameter drift tube (same gun design as that used in tube C-1) and was, thus, difficult to focus properly. Second, an exposed section of the ceramic support rods, between the last antenna and the tube collector, was found to charge to the cathode potential in the presence of the electron beam; as a result it was not possible to collect the beam current.

Because of the factors described above, tube D-1 could be "focused" only by observing its gain and power output, with the tube position being adjusted for maximum response. Under these conditions, it was estimated that the effective beam current in the linear-amplifier section was in the order of 200 ua and that the current in the limiter section was somewhat less, even though the total helix current was about 800 ua.

The data shown in Figure 5(b) were obtained under the above conditions. With the tube adjusted for maximum small-signal gain, the power-output characteristics (Curves I) were obtained. The linear helix

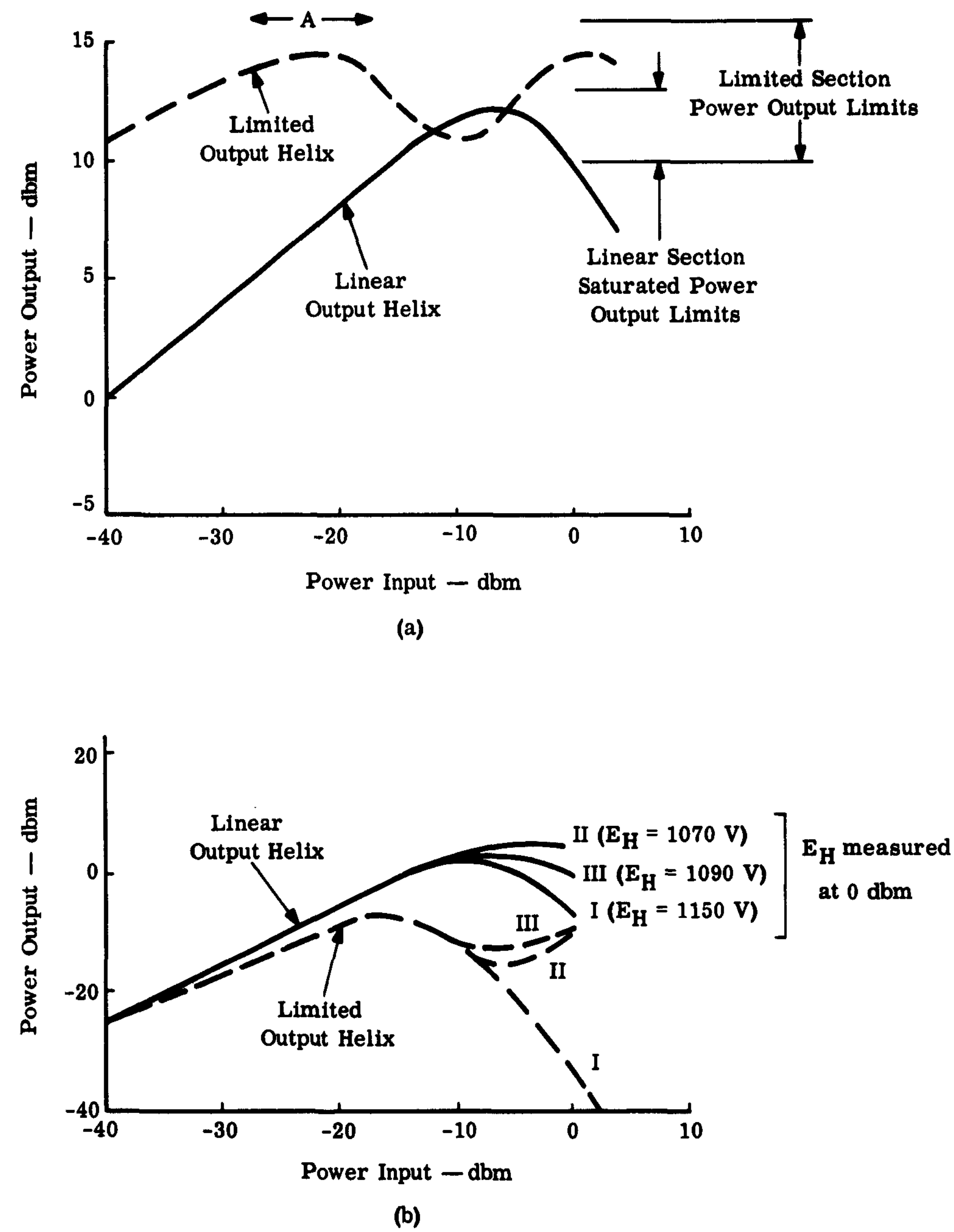


Figure 5 — RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Power output-vs.-power input characteristics of the limited-output helix section. (a) Curves showing the characteristics desired in the final tubes. (b) Plot of the measured characteristics of experimental tube D-1.

section reached saturation with about -7 dbm of input power, as indicated by the characteristic drop in power output with overdrive. The limited helix section reached saturation with about -17 dbm of input power and then dropped more rapidly in the overdrive region.

Curve II was obtained by adjusting the helix potential (in the range of -10 dbm input drive level) for maximum output in the linear helix section. Under these conditions, the linear-section output remained almost constant while the limited-section helix output dipped about 8 db and then returned towards full output at the 0 dbm drive level. Curve III was obtained by adjusting the helix potential for maximum output in the limited helix section. The linear section output again dropped slightly in overdrive, but the power output of the limited helix section, although still fluctuating, was limited to an excursion of about 5 db.

The data taken on tube D-1, while complicated by the poor beam transmission and the unipotential helices, indicated that it should be possible in the final-design tube to (1) properly locate and set the level of the first saturation level of the limited-output helix (Point A in Fig. 5(a)) by means of the separately controlled potential on this helix, and (2) to minimize excursions in the limited-section helix power output, due to the breakup in the beam velocity distribution, by using either selective attenuation or proper adjustments to the limited output helix phase velocity.

The average beam velocity has been reduced about 60 volts for the linear section helix and about 80 volts for the limited section helix (at the 0 dbm drive level). In the proposed final tube design, it is planned to decrease the phase velocity in a portion of the limited section helix by means of additional dielectric loading on the helix. This is readily possible with the compression-sheath-supported helix design. Experimental glass tubes in which the helix structures will approximate the structure shown in Fig. 3(b) are in preparation for evaluation. This is essentially the final-design structure and is expected to closely meet the desired tube specifications. Any further design revisions will be made in metal-ceramic tube designs.

(3) Experimental Tube VF-1

Tube VF-1 was constructed primarily for use in dynamic tests of the video detector, and it contained only a linear-amplifier section and the detector. The electron gun and helix used in this tube were of the same design as those used in tube C-1; however, the helix structure was the compression-sheath-supported type. As reported in paragraph c above, the gun-to-helix alignment in this tube was excellent, which was reflected by the improvement observed in the focusing of its electron beam compared to that of tubes C-1 and D-1. Also, the gas level of tube VF-1 was extremely low, which was attributed to the hydrogen-firing of the helix structure prior to its assembly in the glass envelope.

The rf performance of tube VF-1 was similar to that of tube C-1, as shown in Fig. 4. The video-detection performance is described in paragraph 2, "Design and Evaluation of the Video Section." (A schematic of tube VF-1 is shown, under the discussion of video detection, in Fig. 6.)

2. Design and Evaluation of the Video Section

The video information on the modulated electron beam is to be extracted from the axial electron velocity perturbations that result from the process of modulation. In essence, low-level electron pulses that result from accelerated electrons will be detected and amplified to the desired output levels by means of secondary-emission techniques.

a. Video Detection

The video detector of the A-1281 tube is based upon the principle of a hyperbolic lens operating in the mirror mode. DC tests of a modified version of the lens have yielded the desired transfer curves. In order to evaluate the operation of the lens under actual dynamic conditions, i.e., with an actual modulated electron beam, an experimental tube incorporating the video detector was fabricated.

This tube, VF-1, had essentially the linear helix section of tube C-1 but was constructed using the compression-sheath technique. The schematic of this tube is shown in Fig. 6(a). A uniform magnetic field of about 450 gausses was positioned over approximately 3/4 of the lens region.

A curve of the transmission current through the lens versus the power output of the linear helix section, with the gate electrode G biased to give zero transmission for a DC beam, is shown in Fig. 6(b). The curve was plotted with a constantly increasing power input to the tube, with

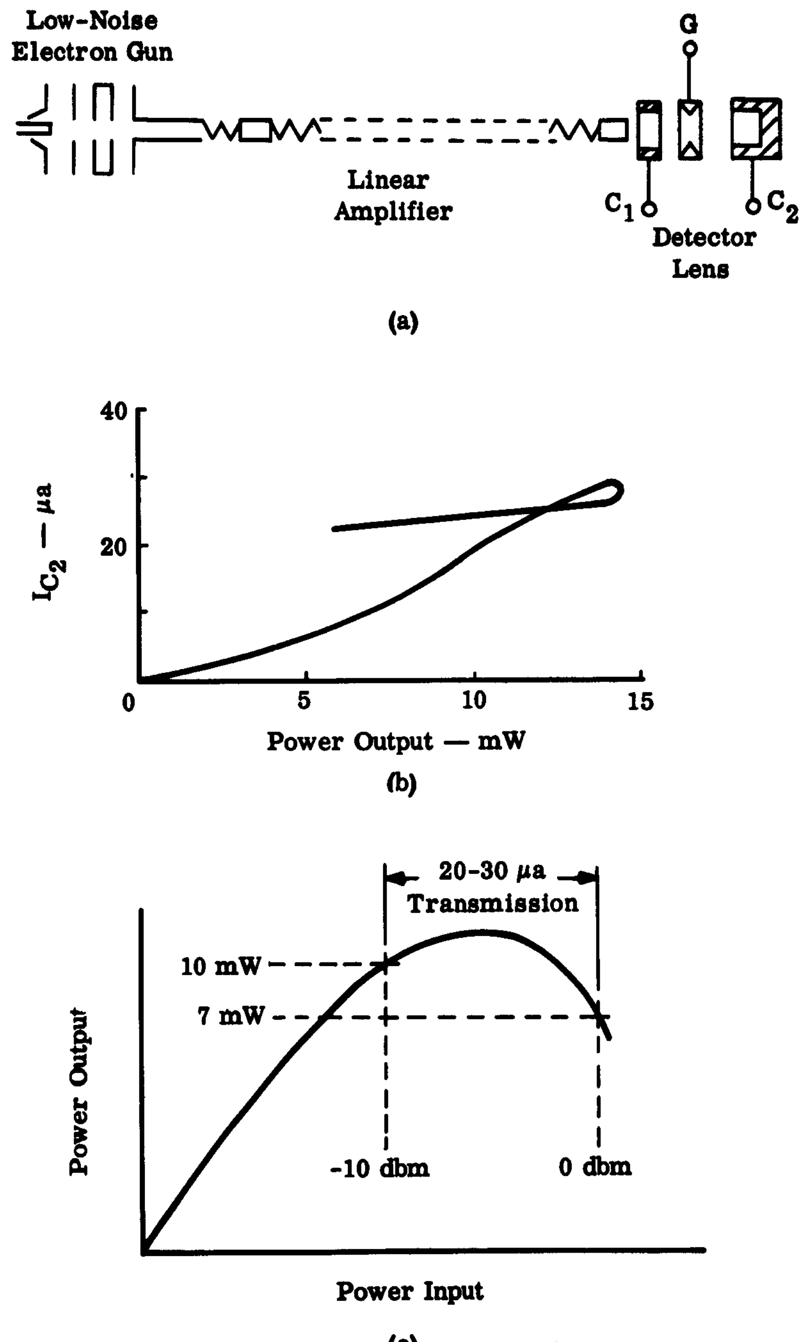


Figure 6 — RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Performance of an experimental tube in the dynamic video-detection tests. (a) Schematic of the tube (tube No. VF-1) used in the tests. (b) Transmission characteristics of the lens for accelerated electrons. (c) Transmission characteristics of the lens as a function of the drive power input.

the output power reaching saturation and then decreasing in overdrive, thus accounting for the fold-back in the curve. This curve shows that the transmitted current decreases slowly in overdrive, exactly the type of operation desired in the final tubes. In obtaining this curve, it was found that with a change in input power from -10 dbm to 0 dbm, Fig. 6(c), the current transmitted through the lens ranged between 20 and 30 ua. In this test, only about 300 ua was actually focused as far as the lens. About 200 ua was defocused to the output antenna (without adversely affecting the rf characteristics, however) because electrodes C1 and C2, Fig. 6(a), were depressed to about 700 volts below the helix potential. In this test, the magnetic circuits in this region were not re-adjusted for the lower beam velocities. Depression of these electrodes is preferable for best lens operation, as was shown in Interim Development Report No. 2. In the final-design tube, C2 is actually the first dynode of the secondary-emission amplifier and the desired operating potential of this electrode is 300 to 400 volts above the cathode. Since the helix is about 1250 volts above the cathode, the potential of the first dynode will satisfy both the gating requirements of the lens and the secondary-emission requirements.

In the final-design tube, the limiter section is designed so as to provide sufficient accelerated electrons in the electron beam over the range -40 to 0 dbm. The beam current in the helix regions will be between 500 and 600 ua. A suitable transition region from the main PPM field over the helix to the uniform field over the lens will be used to keep the beam focused in the depressed collector region. A transmitted beam current between 40 and 60 ua will be available at the first dynode of the secondary-emission amplifier under rf conditions, with the power inputs between -40 and 0 dbm.

The evaluation of tube VF-1 was complicated to some extent by the charging of the ceramic spacers used to separate the electrodes of the lens system. A higher-value uniform magnetic field (525 gausses) was placed over the lens in an attempt to minimize or eliminate charging tendencies, but the tube was broken in trying to focus it under these conditions.

The charging of the ceramics was probably due to (1) the large excursions of the electrons in the lens region, (2) the defocusing of the beam due to the depressed collector potential, and (3) the large transverse electric field perturbations on the lens symmetry because of the closeness of the lens-electrode leads on both sides of the lens gate. In the final design of the metal-ceramic tube, the ceramics are spaced farther from the electron beam and are partially shielded, while dc lead connections will be made radially to the electrodes. These features plus the proper magnetic field configurations, should eliminate any possibility of charging the ceramic spacers in this region.

b. Video Amplification

The current pulses (video signal) of the order of 40-60 ua, which will be available from the video detector, must be amplified in the order of 100 times to develop the required one-volt video signal across the 300-ohm output termination.

A simple, 3-stage, crossed-field type of secondary-emission (S.E.) video amplifier was developed for use with the A-1281 tube. (See Interim Development Report No. 2.) Initial evaluations of an amplifier, which was built into a large-diameter glass structure, were somewhat limited due to the fact that, because of the physical limitations imposed by the large-diameter glass used, only fringing magnetic fields could be used in the dynode regions.

A small-diameter glass envelope version of the amplifier was built and tested. The diameter of the glass bulb was about the same as the proposed metal-ceramic version of the amplifier and allowed for the proper concentration of the magnetic field. Some of the pertinent data obtained in these tests are given below.

(1) Maximum Gain

Under optimum conditions of magnetic field and dynode voltages, the maximum gain achieved for the three-stage S.E. amplifier was 120. The input beam current for this gain was 10 ua, and the output current was 1.2 ma.

(2) Maximum Current

The maximum current observed at the collector of this test tube was 10 ma and was obtained with an overall amplifier gain in the order of 50, i.e., the input current was about 200 ua. While the proposed tube will operate at a maximum collector current of but 4 ma, the data are significant in that the output dynode had saturated at the 10 ma level, probably due to some physical deterioration plus thermal effects. Continued dc operation of the output dynode above the 7 ma level resulted in a permanent deterioration of the dynode gain.

(3) Operation Using Regulated Supply Voltages

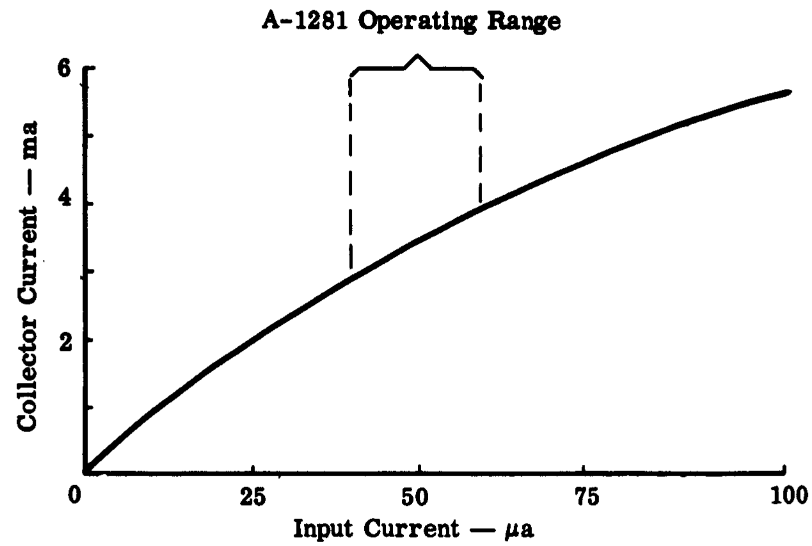
The curve of Fig. 7(a) was obtained by operating the dynodes at fixed potentials (using regulated power supplies) and suitable transverse magnetic fields as shown below:

Dynode	Voltage	Magnetic Flux Density
1	470 volts	50 gausses
2	760 volts	400 gausses
3	1000 volts	460 gausses

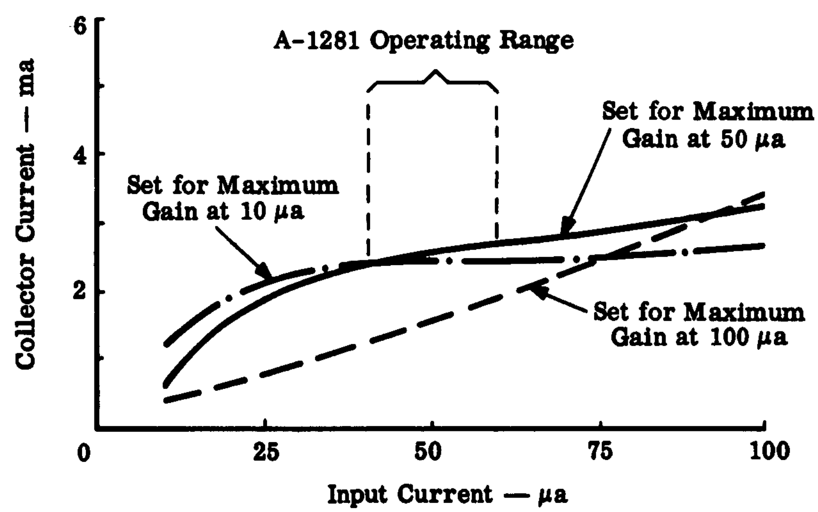
The collector voltage was maintained at 1270 volts. At input drives of 40 to 60 ua, the expected operating range in the final-design tube, the output current ranged between 3 and 4 ma. This is adequate for the desired video output characteristic.. Above 7 ma of collector current, some dynode arcing occurred, and the dynodes showed some color due to heating. The final metal-ceramic version of the S.E. video amplifier will be able to operate at much higher current levels primarily because of (1), the low duty cycle of operation under the pulsed conditions, and (2) the much better dissipation of thermal energy possible in these metal-ceramic structures.

(4) Operation Using a Resistor Divider Network

When the dynode voltages were applied through a resistor network, variations in currents drawn from the dynodes caused changes in the voltages at the individual dynodes, as expected. In general, the dynode voltages increased toward the collector voltage with increasing current.



(a)



(b)

Figure 7 — RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. Performance of the secondary-emission video amplifier. (a) Operation with individual dynode voltages applied from a regulated power supply. (b) Operation with dynode voltages obtained from a resistor voltage-divider network.

The changes in the dynode voltages introduce two other changes that affect the gain of the amplifier. First, the secondary-emission ratio,, δ , of the individual dynodes varies with changes in the dynode voltage. Second, the path along which the beam is guided under the crossed-field conditions is distorted by the dynode-voltage-changes -- i.e., defocusing of the beam occurs. Since the beryllium-oxide dynodes have a relatively flat δ -versus-voltage curve, the defocusing of the beam has a far greater effect on amplifier gain. The behavior of the amplifier when using a resistor divider network is shown in Fig. 7(b). For these measurements, the amplifier was set up as shown in Fig. 6 of Interim Development Report No. 2. The resistors comprising the divider network were each 180,000 ohms. The overall supply voltage was 1250 volts.

Each of the curves in Fig. 7(b) was taken with the magnetics adjusted to give maximum collector current at a different input current level; as a result large variations in gain were observed. When the magnetics were adjusted at an input current of 10 ua, the collector current at 10 ua input was 1.2 ma, giving a gain of 120. When the magnetics were set for a maximum gain at 100 ua, the collector current at 10 ua was only 0.35 ma, giving a gain of but 35 at the 10 ua input level. Thus, the gain dropped at the low end, whereas it increased somewhat at the high end, simply by adjustment of the magnetics, which primarily changed the beam guidance paths. There is, of course, an effect on the gain due to changes in the δ , but this turns out to be a second order effect.

The use of "focusing" action, as seen above, in controlling the amplifier gain level will have an effect on the pulse rise time. However, this should never be greater than a 10 to 20 nanosecond degradation. This was borne out by observation of pulse shapes on the above experimental tube with a wide-band oscilloscope. The rise time of the output pulse was the same as the rise time of the pulse generator itself (approximately 100 nanoseconds), so that the rise time of the S.E. amplifier is better than 100 nanoseconds.

(5) Limiting Action

The design objective for the video section is to develop a one-volt ± 3 db output across the 300-ohm termination. This, of course, implies a limiting action. The video output of the A-1281 will be effected by two fluctuations: (1) The variation in detector current with changing rf drive, and (2) the changes in gain of the S.E. amplifier with the changing detector current.

The detector current was seen to be relatively constant even when the detector followed the linear-amplifier section (as in tube VF-1.) Since in the A-1281 tube, the detector will actually follow the limiter section, the input current to the S.E. amplifier should be constant to within 30 to 50 per cent. For this range of variation in the incident current, it has been shown that the collector current can be held constant to within 10 per cent. This capability is shown by the curve of Fig. 7(b) where the magnetics were adjusted for maximum gain at 10 ua of incident current. The lower levels of output current seen in Fig. 7(b) are the result of dynode deterioration with high-level current operation, rather than a fundamental limitation of the resistor network system.

Therefore, by proper selection of all operating parameters, the objective specifications for the video output should be easily obtained. Under the proposed operating conditions, the S.E. amplifier will not be a limiting factor to the life of the A-1281 tube. In fact, a slight radial shift in the alignment of the video section magnetic circuits should extend dynode life many times (as well as "repair" accidental damage to the dynodes.)

(6) Expected Final Operating Conditions

The objective specifications of 1 volt $\pm$ 3 db across 300 ohms will be met as follows:

One volt $\pm$ 3 db corresponds to 0.7 to 1.41 volts or 2.3 to 4.7 ma through the 300 ohm resistor. From Fig. 7(a), a current of 35 to 65 ua incident on the first dynode will give a collector current of 2.5 to 4.2 ma. These results are based upon dynode supply voltages which were regulated. With the resistor divider network planned for use with the A-1281 tube, the output voltage will be much more constant as is seen in the curves of Fig. 7(b).

3. Design and Construction of the Metal-Ceramic Tube

The basic subassemblies of the metal-ceramic version of the A-1281 tube are constructed as separate units which can be subsequently brazed or welded together to form an integral tube structure. These units are the electron gun assembly, the helix assembly, and the video assembly.

a. The Electron Gun

The proposed metal-ceramic structure for the electron gun was shown in Fig. 3 of Interim Development Report No. 2. Both lap-type and butt-type of metal-ceramic seals have been investigated for the envelope structure. Present indications are that butt-type seals may be preferable for the final-design version of the A-1281 tube.

The fabrication of the gun-stem assembly, using a machined ceramic button stem with brazed leads as shown in the Fig. 3 referred to above, has been delayed due to delay in vendor deliveries. An alternate built-up type of stem assembly has been made, using commercially available ceramic terminals. This design is now being developed for use in the final-version A-1281 tube.

Parts, fixtures, and techniques of brazing are being evaluated and standardized in preparation for the metal-ceramic-tube evaluation phase of the program.

b. Slow-Wave Structures

Compression-sheath-supported helix structures have been developed to the point where strong, reproducible subassemblies can now be made consistently. In the initial helix envelope structure (see Fig. 1, Interim Development Report No. 2), lap-type compression seals are used for the helix antenna windows. An investigation is also planned of the use of the butt-type ceramic seal in window construction, probably in conjunction with a metallized ceramic envelope. Again, techniques and procedures are being standardized in preparation for the metal-ceramic-tube evaluation phase of the program.

c. The Video Section

The metal-ceramic video section depicted in Fig. 8 of Interim Development Report No. 2 is being modified slightly. Dynode lengths are being

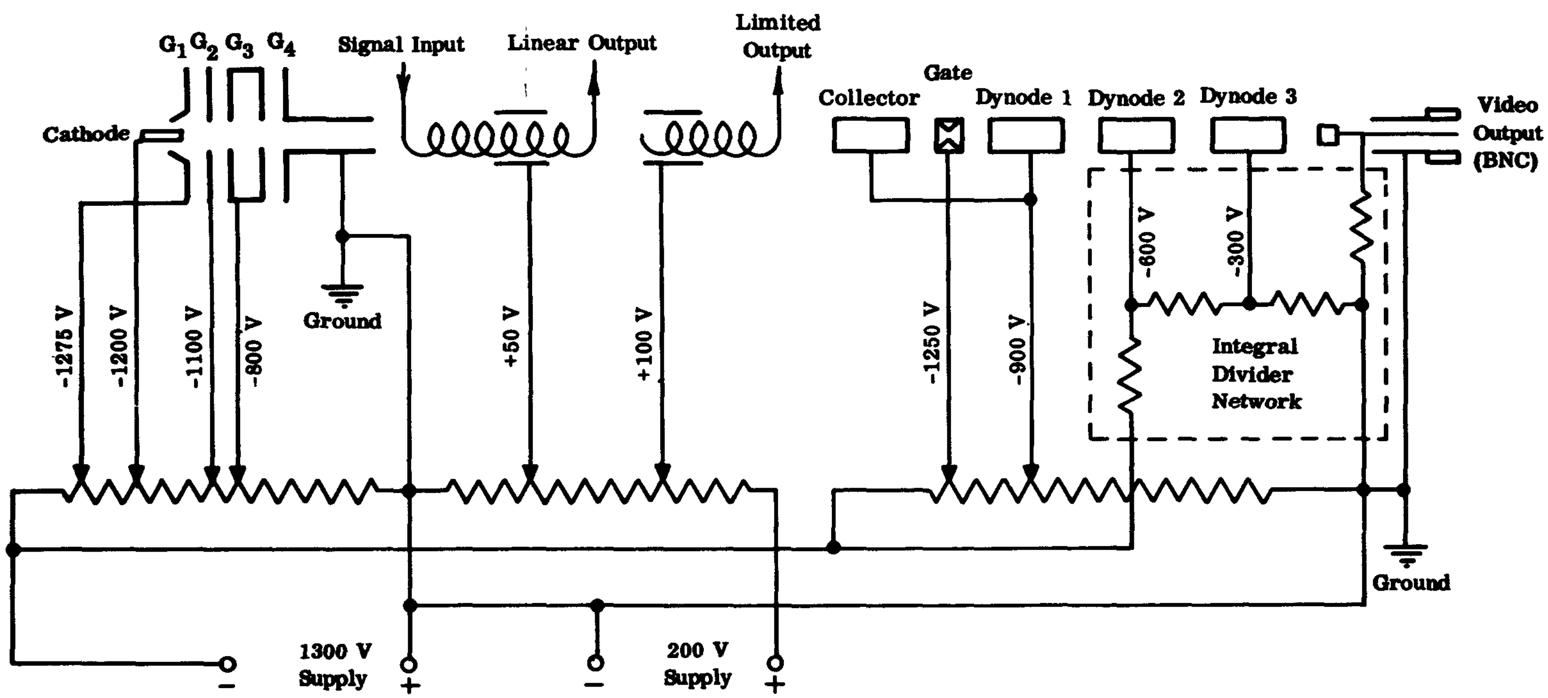


Figure 8 — RCA A-1281 Developmental Multiple-Function, X-Band Traveling-Wave Tube. DC supply voltages that, at present, are expected to be required in the final tube.

adjusted as a result of the S.E. amplifier tests which have been made, and the video section diameter is being reduced in order to allow for its passage through the final-design waveguide choke sections. Simplification of the S.E. amplifier to a 2-stage unit is possible if more than 100 ua of detected video current is available in the final design tube.

Techniques and procedures of assembly are also being refined in preparation for the metal-ceramic- tube evaluation phase of the program.

d. Overall Package Design and Development

All exploratory and experimental work reported thus far has been performed in experimental types of focusing packages which enabled changes in couplers, coupler positions, magnetics, and other experimental adjustments. Now that the final design of the focusing system has been established, work is progressing on the design of the final package. The emphasis is being placed on the development of a package that will be relatively simple to construct and that will be sufficiently rugged to provide highly reliable performance under the required environmental conditions.

In addition to the work on the design of the final package, effort is also being expended to establish, and to simplify as much as possible, the power-supply requirements of the A-1281 tube. The voltage divider arrangement shown in Fig. 8 indicates the supply voltages that, at present, are considered necessary for satisfactory operation. The arrangement shown in the figure is not intended to represent the final setup that will be used to apply power to the final tubes. The wide variations in current drains, particularly in the video section, may not permit the use of a simple voltage divider circuit.

The video section presents a special problem in determining the current drain on the power supply because the L-C-R constants of this circuit will have to be adjusted for best pulse response. Accordingly, since the constants of the video section have not been firmly established and because the final evaluations of the metal-ceramic tubes may indicate that changes are necessary, the arrangement and electrode voltages indicated in Fig. 8 must be considered tentative.

B. Project Performance and Schedule Chart

The chart on the following page summarizes the work done thus far toward the objectives of the program and shows the schedule to be followed for all projected operations.

C. Conclusions

The development work performed and the experimental tube evaluations made during this period have resulted in the following conclusions:

1. The basic helix parameters of the final-design tube have been confirmed in experimental tube tests. Limiter action tests, while complicated by several factors which will not be present in final-design tubes, gave indications that limiter performance will be as desired.

2. The compression-sheath-helix structure is proving to be a strong, reproducible, and gas-free assembly. The structure is also sufficiently flexible so that any design refinements necessary, as a result of the prototype tube evaluations, can be readily made.

3. Tests of interim tubes, using drift tubes of smaller ID than that proposed for the final-design tube, had severely degraded noise performance. However, this same factor necessitated refinement of the magnetic focusing circuits to the point where substantial improvement and advantage will be achieved in the final-design tubes.

RADIO CORPORATION OF AMERICA

PROJECT PERFORMANCE AND SCHEDULE
(Project No. SR008-03-04 Task No. 9293 Sub.)

Contract NObsr-87535

Report Date: March 29, 1963

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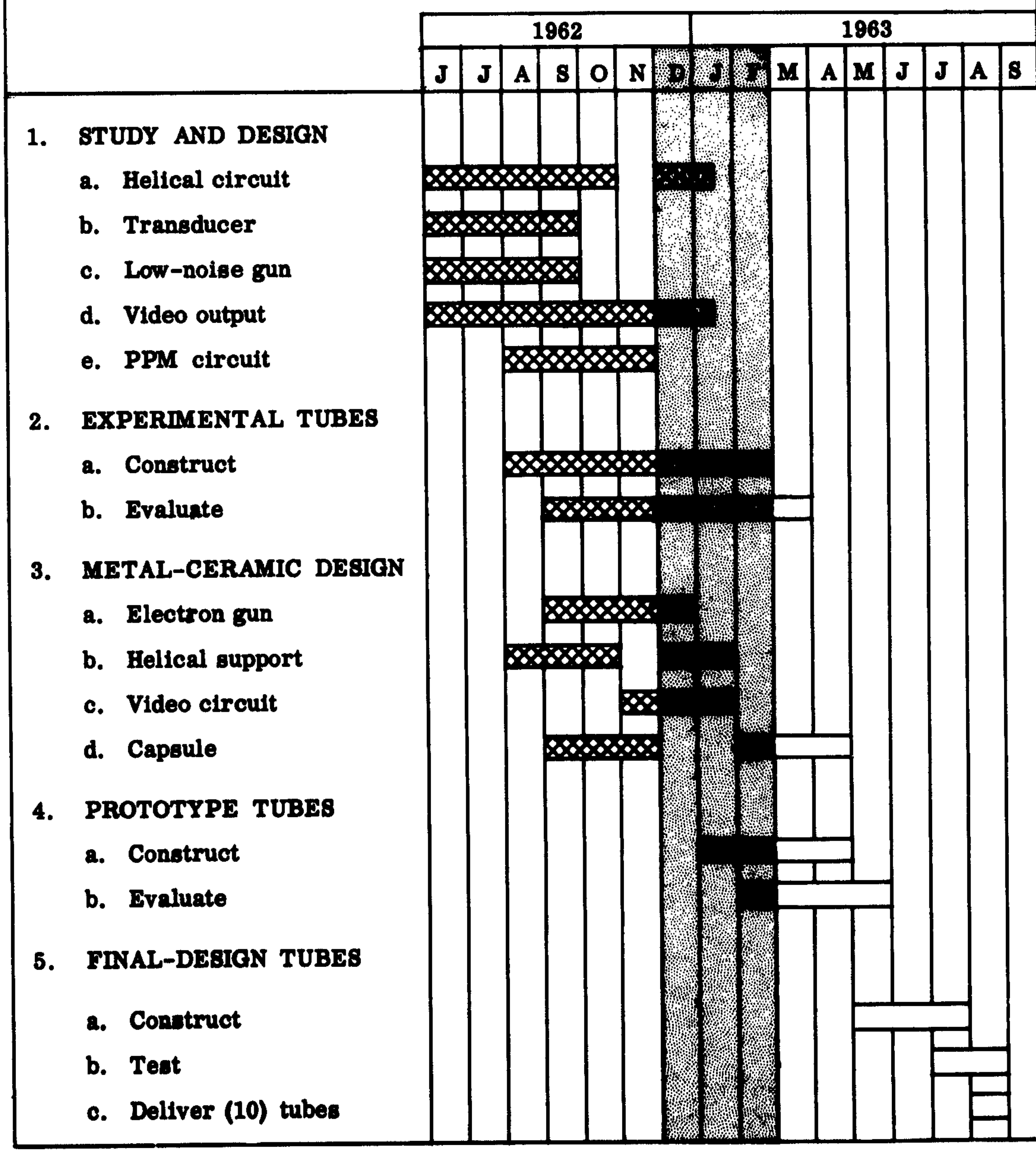

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PROJECT PERFORMANCE AND SCHEDULE (SHEET 2)
(Project No. SR008-03-04, Task No. 9293 Sub.)

Contract NObsr-87535

Report Date: March 29, 1963

Period Covered 12/1/62 to 2/28/63

Legend: Work Performed

Schedule of Projected Operation

Item: Estimated Completion in Percent of <u>Total Effort</u> Expected to be Expended (Not Chronological).

1. Study and Design 90%
2. Experimental Tubes 80%
3. Metal-Ceramic Design 70%
4. Prototype Design 40%
5. Final Design Tubes 0%

4. Video-detection performance was tested under dynamic beam conditions. The detector operation was essentially as initially proposed.

5. Secondary-emission amplifier tests were made using a dc beam from an electrostatically focused low-noise electron gun. Again, the performance was essentially as proposed, and the operating conditions in the final-design tube and related circuitry were worked out.

6. The basic design of metal-ceramic tube is essentially complete. The current effort is largely directed toward developing techniques and procedures which will increase the yield and reliability of the seals.

In summary, much progress has been made in the program to develop the A-1281 multiple-function tube. However, the program is now about one month behind schedule, largely due to the additional effort which was necessary for the perfection of the compression-sheath helix structures and the refinements required of the PPM focusing system.

PART II

PROGRAM FOR NEXT INTERVAL

PROGRAM FOR NEXT INTERVAL

1. Complete evaluation of prototype tubes fabricated in glass or of hybrid glass-metal ceramic construction.

2. Continue metal ceramic technology development with emphasis on production techniques. Ceramic to metallized ceramic structures are to be given special emphasis.

3. Fabricate and evaluate prototype tubes of all metal-ceramic construction. Include design refinements as necessary.

4. Complete design of overall tube package. Determine initial environmental capabilities.

5. Prepare for sample tube production: Order vendor-supplied parts; Review manufacturing drawings and processing data.

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